

RESONANCES AND EXCLUSIVE CHANNELS: AN EXPERIMENTER'S SUMMARY

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A very remarkable number of new results in the study of resonances and exclusive channels has been presented at this conference giving fundamental information in the understanding of strong interactions at low energies. The first results from the new high luminosity colliders are impressive and a lot of activity in this field is foreseen for the future. The most relevant issues are summarized and discussed in this paper.

1 Introduction

The study of resonances and exclusive channels mostly aims to understand the behaviour of the strong interactions in the energy range up to a few GeV. Here perturbative QCD cannot in general be applied and phenomenological models are needed to interpret the data which are often used as input to the models themselves. In this energy range the quarks and the antiquarks form a large number of bound states which are commonly interpreted as mesons and baryons.

In this scheme a fundamental question is still open: do glueballs exist? According to QCD, bound states of one or more gluons can be formed but a solid experimental observation is still missing. The search for this form of matter made only by boson force carriers is one of the most actual themes of research in this field.

Because of the large mass of the charm quark, the study of the formation of charmonium states allows to test non-relativistic perturbative QCD calculations and to measure α_s at the charm scale.

Two-photon collisions at electron positron storage rings represent a very good and clean environment for this kind of studies ¹. Since gluons do not couple directly to photons, the two-photon process is a powerfull glueball anti-filter.

In the last few years a very remarkable progress has been achieved due to the results of many experiments. Considering two-photon physics, LEP at CERN and CESR at Cornell have produced a large number of important

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results. At this conference the first results from the new e^+e^- high luminosity machines DAΦNE at LNF and BELLE at KEK have been presented. These results are impressive and sometimes already comparable with the achievements of the machines of the previous generation. A bright future for this field of research is therefore foreseen.

2 Lepton, meson and baryon pair production in two-photon collisions

The study of lepton pair production is a test for QED and an important tool to understand experimental apparatuses. The production of muon ² and τ pairs ³ is studied by L3 and bounds for anomalous couplings of the τ lepton are set for the first time in this kind of studies.

Charged kaon and pion pair production in two-photon collisions is studied by ALEPH and DELPHI ⁴. Good agreement is found between the experimental results and the Brodsky-Lepage model for the kaons. For the pions there is not good agreement either between the two experimental measurements or between experiment and theory. More work is therefore required to understand the data.

The study of baryon-antibaryon pairs allows to test the predictions of pure quark and quark-diquark models. From the study of the reaction $\gamma\gamma \rightarrow p\bar{p}$ presented by OPAL ⁵ it is difficult to have an indication on which model reproduces better the data. The preliminary results of the same channel presented by BELLE ⁶ show that this channel will be studied with a much larger data sample in the near future. The production of Λ and Σ^0 baryon pairs is studied by L3 ⁷ and good agreement is found with the quark-diquark model predictions. The pure quark model is disfavoured by this analysis.

3 Pseudoscalar and vector mesons

The precise measurements of $BR(\Phi \rightarrow \eta'\gamma)$ and of the ratio $BR(\Phi \rightarrow \eta'\gamma)/BR(\Phi \rightarrow \eta\gamma)$ by KLOE ⁸ disfavor models with a large gluonium content in the η' . This is in agreement with the previous results obtained by L3 ⁹ in two-photon collisions.

The $K_S^0 K^\pm \pi^\mp$ and $\eta \pi^+ \pi^-$ final states in two-photon collisions are studied by L3 ¹⁰. The formation of the $\eta(1440)$ and of the $f_1(1420)$ as a function of Q^2 is investigated for the first time, showing that also vector mesons can be studied using the two-photon process if a large data sample is available. The two-photon width of the $\eta(1440)$ is obtained using data at low Q^2 , as reported in Table 2. This first observation of the $\eta(1440)$ in untagged two-

photon collisions disfavors its interpretation as the 0^{-+} glueball in agreement with the lattice QCD calculations. The $\eta(1440)$ can therefore be interpreted as a radial excitation ¹¹.

The first sign of the production of an η_b meson may have been shown for the first time at this conference by ALEPH ¹².

4 Scalars, tensors and glueball searches

The tensor meson nonet is well established and is nowadays used as a test for other measurements. On the other hand, the interpretation of the scalar meson nonet is still an open and important problem to be solved. According to lattice QCD predictions ¹³, the ground state glueball is a scalar with a mass between 1400 and 1800 MeV and the tensor glueball is heavier with a mass between 1900 and 2300 MeV. Since several 0^{++} states have been observed in the 1400-1800 MeV mass region, the scalar ground state glueball can mix with nearby quarkonia, making the search for the scalar glueball and the interpretation of the scalar meson nonet a single problem ¹⁴. The interpretation of the 1400-1800 MeV mass region is made even more difficult by the fact that radially excited tensor meson states are also predicted in this mass region.

The $\pi^+\pi^-\pi^0$ final state in two-photon collisions, studied by L3 ¹⁵ and BELLE ¹⁶, is dominated by the formation of the $a_2(1320)$. These studies clearly confirm the observation of the radially excited tensor meson $a_2'(1750)$, already reported by L3 in a previous study ¹⁷. The values obtained for the two-photon width (Table 2) by the two experiments are consistent and agree with the theoretical predictions ¹⁸. The spin-parity analysis performed by L3 shows some indications for other states which will be possibly put in evidence in future as soon as larger data samples will be available.

The $K\bar{K}$ final state in two-photon collisions is largely dominated by resonance formation and is therefore one of the golden channels in the study of scalar and tensor states. A final study of the $K_S^0 K_S^0$ final state is reported by L3 ¹⁹ and a preliminary study of the $K_S^0 K_S^0$ and the $K^+ K^-$ final states is presented by BELLE ²⁰. The two $K_S^0 K_S^0$ mass spectra show nearly identical

Table 1. Spin and helicity studies of the $K\bar{K}$ final state by L3 and BELLE.

	$K_S^0 K_S^0$ (L3)	$K_S^0 K_S^0$ (BELLE)	$K^+ K^-$ (BELLE)
$f_2'(1525)$	(J=2, $\lambda=2$) only	(J=2, $\lambda=2$) only	(J=2, $\lambda=2$) only
1750 MeV	(J=2, $\lambda=2$) dominant	(J=0) dominant	(J=2, $\lambda=0$) dominant

features. Around 1300 MeV a small signal is due to the $f_2(1270)$ - $a_2(1320)$ destructive interference. The spectrum is dominated by the formation $f'_2(1525)$ tensor meson for which the two-photon width is measured with high precision by L3, as reported in Table 2. A very clear signal is present around 1750 MeV, exactly where the $s\bar{s}$ member of scalar meson nonet and the radially excited tensor mesons are expected. To investigate the spin J and the helicity λ , the decay angular distributions are studied, as reported in Table 1. Good agreement is found only in the $f'_2(1525)$ mass region while the interpretation of the 1750 MeV mass region is still unclear. L3 reports a measurement of the two-photon width of the $f_2(1750)$ (Table 2), in agreement with the theoretical predictions for the radially excited tensor mesons¹⁸. More than one wave is very probably present in this mass region. The presence of a $J=0$ state reported by L3 with a fraction of $24\pm 16\%$ and by BELLE, if confirmed, is very important to support the interpretation of the $f_0(1300)$, the $f_0(1500)$ and $f_0(1750)$ as the two isoscalar members of the scalar nonet mixed with the ground state glueball¹⁴. If this is the case, the $f_0(980)$ and the $a_0(980)$ cannot be considered as $q\bar{q}$ states, as suggested by the recent results by KLOE⁸ in the study of the decays $\Phi \rightarrow a_0(980)\gamma$ and $\Phi \rightarrow f_0(980)\gamma$.

No evidence for the observation of the narrow $\xi(2230)$ tensor glueball candidate²¹ is reported by L3¹⁹ and BELLE²⁰. Upper limits for the two-photon width of the $\xi(2230)$ are derived, in agreement with the results by CLEO²² (Table 2). This is in favour of the interpretation of the $\xi(2230)$ as the tensor glueball in case of a confirmation in gluon rich environments or is just an indication that this state simply does not exist.

5 Charmonia

New preliminary results on the formation of the $\eta_c(2980)$ have been submitted by DELPHI²³. The two-photon width is measured using the $K_S^0 K^\pm \pi^\mp$, $K^+ K^- K^+ K^-$ and $K^+ K^- \pi^+ \pi^-$ decay modes leading to the combined result reported in Table 2. This measurement is in good agreement with the previous measurements²¹ and with the theoretical predictions²⁴. No signal of the η_c is observed in the $\pi^+ \pi^- \pi^+ \pi^-$ final state and the upper limit $\Gamma_{\gamma\gamma}(\eta_c) < 3.8$ keV is derived. This contradictory problem is still under investigation.

Two new measurements of the two-photon width of the χ_{c2} have been presented in this conference by BELLE²⁰ and CLEO²⁵, as presented in Table 2. It is interesting to remark that the measurement by BELLE is based on the “usual” $J/\psi\gamma$ decay mode while CLEO performs the first measurement using the $\pi^+ \pi^- \pi^+ \pi^-$ decay mode.

The measurements of the two-photon width of the η_c performed in two-

photon collisions are in good agreement with the ones obtained in $p\bar{p}$ annihilations²¹. The situation is different for the χ_{c2} . The measurements of the two-photon width of the χ_{c2} performed in two-photon collisions and using the $J/\psi\gamma$ decay mode are significantly higher than the values measured in $p\bar{p}$ annihilations²¹. The reason for this could be due to a systematic effect affecting the two-photon measurements based on the $J/\psi\gamma$ decay mode. As a matter of fact, this new measurement by CLEO is surely not affected by the same systematic effects and is in better agreement with the measurements obtained in $p\bar{p}$ annihilations.

The first measurement of the two-photon width of the χ_{c0} is obtained by CLEO²⁵. The result is reported in Table 2 and is obtained using the $\pi^+\pi^-\pi^+\pi^-$ decay mode. An indication for the formation of the χ_{c0} is present in the $K_S^0 K_S^0$ mass spectrum presented by BELLE²⁰. If confirmed, it will be interesting to have the possibility to perform a completely independent measurement of the two-photon width of the χ_{c0} .

6 Conclusions and outlook

The study of resonances and exclusive channels is a very interesting and active field of research. A remarkable progress on the study of resonance formation in two-photon collisions has been achieved in the last few years. Data from the LEP collider at CERN and CESR at Cornell allowed to improve significantly the precision on the two-photon widths of several resonances, to identify some radial excitations and to search for glueball candidates. New high luminosity e^+e^- machines have been built and are now starting their data taking. The first results from BELLE at KEK and KLOE at LNF represent a good sign for the future and new projects like CLEO-c³⁰ are welcome. The most relevant recent results on resonance formation in two-photon collisions are summarized in Table 2 and represent an important contribution to meson spectroscopy and glueball searches.

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Table 2. The most recent results on the two-photon width of mesons, charmonia, radial excitations and glueball candidates. (\dagger the value is given times the decay branching ratio)

Resonance	Experiment	Final state	J^{PC}	$\Gamma_{\gamma\gamma}$	Ref.
$\eta'(958)$	L3	$\pi^+\pi^-\gamma$	0^{-+}	$4.17\pm 0.10\pm 0.27$ keV	⁹
$a_2(1320)$	L3	$\pi^+\pi^-\pi^0$	2^{++}	$0.98\pm 0.05\pm 0.09$ keV	¹⁷
$f'_2(1525)$	L3	$K_s^0 K_s^0$	2^{++}	$0.085\pm 0.007\pm 0.012$ keV	¹⁹
$\eta_c(2980)$	L3	9 chan.	0^{-+}	$6.9\pm 1.7\pm 0.8$ keV	²⁶
$\eta_c(2980)$	DELPHI	3 chan.	0^{-+}	$13.0\pm 2.7\pm 5.0$ keV	²³
η'_c	L3	9 chan.	0^{-+}	< 2.0 keV	²⁶
$\chi_{c2}(3555)$	L3	$l^+l^-\gamma$	2^{++}	$1.02\pm 0.40\pm 0.15$ keV	²⁸
$\chi_{c2}(3555)$	OPAL	$l^+l^-\gamma$	2^{++}	$1.76\pm 0.47\pm 0.37$ keV	²⁷
$\chi_{c2}(3555)$	BELLE	$l^+l^-\gamma$	2^{++}	$0.84\pm 0.08\pm 0.10$ keV	²⁰
$\chi_{c2}(3555)$	CLEO	$\pi^+\pi^-\pi^+\pi^-$	2^{++}	$0.53\pm 0.15\pm 0.23$ keV	²⁵
$\chi_{c0}(3415)$	CLEO	$\pi^+\pi^-\pi^+\pi^-$	2^{++}	$3.76\pm 0.65\pm 1.81$ keV	²⁵
$\eta(1440)$	L3	$K_s^0 K^\pm \pi^\mp$	0^{-+}	$0.199^\dagger\pm 0.52$ keV	¹⁰
$f_2(1750)$	L3	$K_s^0 K_s^0$	2^{++}	$0.049^\dagger\pm 0.011\pm 0.013$ keV	¹⁹
$a'_2(1752)$	L3	$\pi^+\pi^-\pi^0$	2^{++}	$0.29^\dagger\pm 0.04\pm 0.02$ keV	¹⁷
$a'_2(1752)$	BELLE	$\pi^+\pi^-\pi^0$	2^{++}	$0.27^\dagger\pm 0.02\pm 0.04$ keV	¹⁶
$f_0(1500)$	ALEPH	$\pi^+\pi^-$	0^{++}	$< 310^\dagger$ eV	²⁹
$f_0(1710)$	ALEPH	$\pi^+\pi^-$	0^{++}	$< 550^\dagger$ eV	²⁹
$\xi(2230)$	CLEO	$\pi^+\pi^-$	2^{++}	$< 2.5^\dagger$ eV	²²
$\xi(2230)$	CLEO	$K_s^0 K_s^0$	2^{++}	$< 1.3^\dagger$ eV	²²
$\xi(2230)$	L3	$K_s^0 K_s^0$	2^{++}	$< 1.4^\dagger$ eV	¹⁹

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